AMS Annual Meeting 2011
Seattle Washington

Boundary layer remote sensing with combined active and passive techniques: GPS radio occultation and high-resolution stereo imaging (WindCam) small satellite concept

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15th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans and Land Surface (IOAS-AOLS)
Paper 6.3

Outline

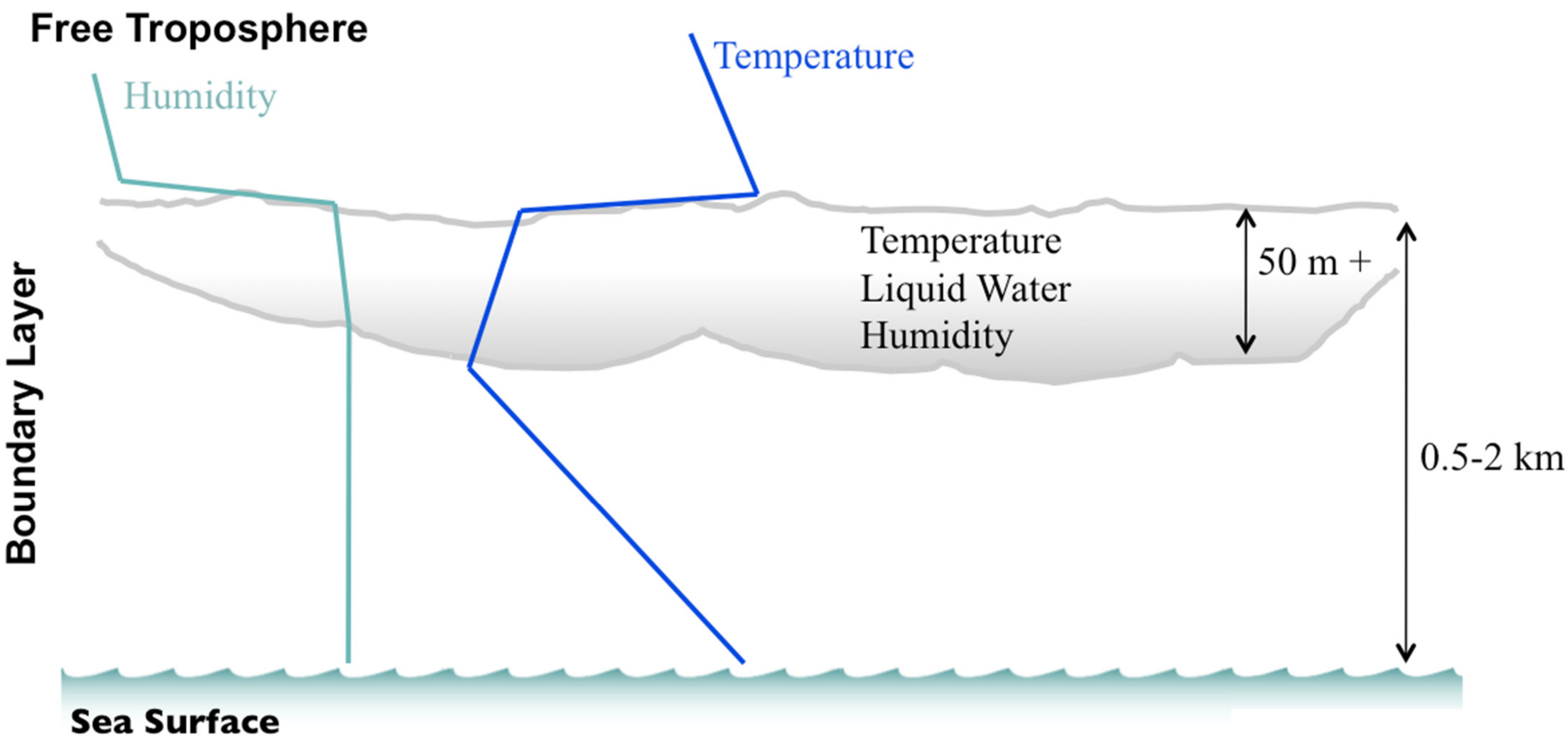
1. **Remote Sensing Challenges: Cloudy Boundary Layer**
2. **Examples of radio occultation (RO) in the Boundary Layer**
3. **A BL Remote Sensing Concept**
4. **Conclusions**

Low-cloud feedback is the largest uncertainty in determining climate sensitivity to greenhouse gas warming (differences in 2xCO_2 sensitivity ~2 K)

Albedo!

What processes govern the structure and variability of the cloudy atmospheric boundary layer?

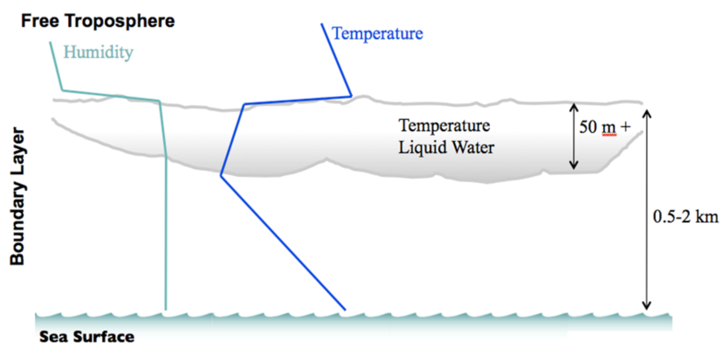
Remote Sensing Challenges



Remote Sensing Challenges – Help Is Here

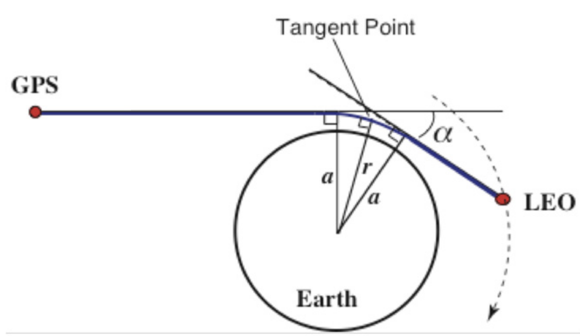
GPS Radio Occultation:

- **Penetrates cloud/insensitive to liquid water**
- **Sensitive to sharp vertical layers**
- **Information on temperature and humidity structure, in particular, sharp vertical layers**



$$N = a_1 \frac{P}{T} + a_2 \frac{P_W}{T^2}$$

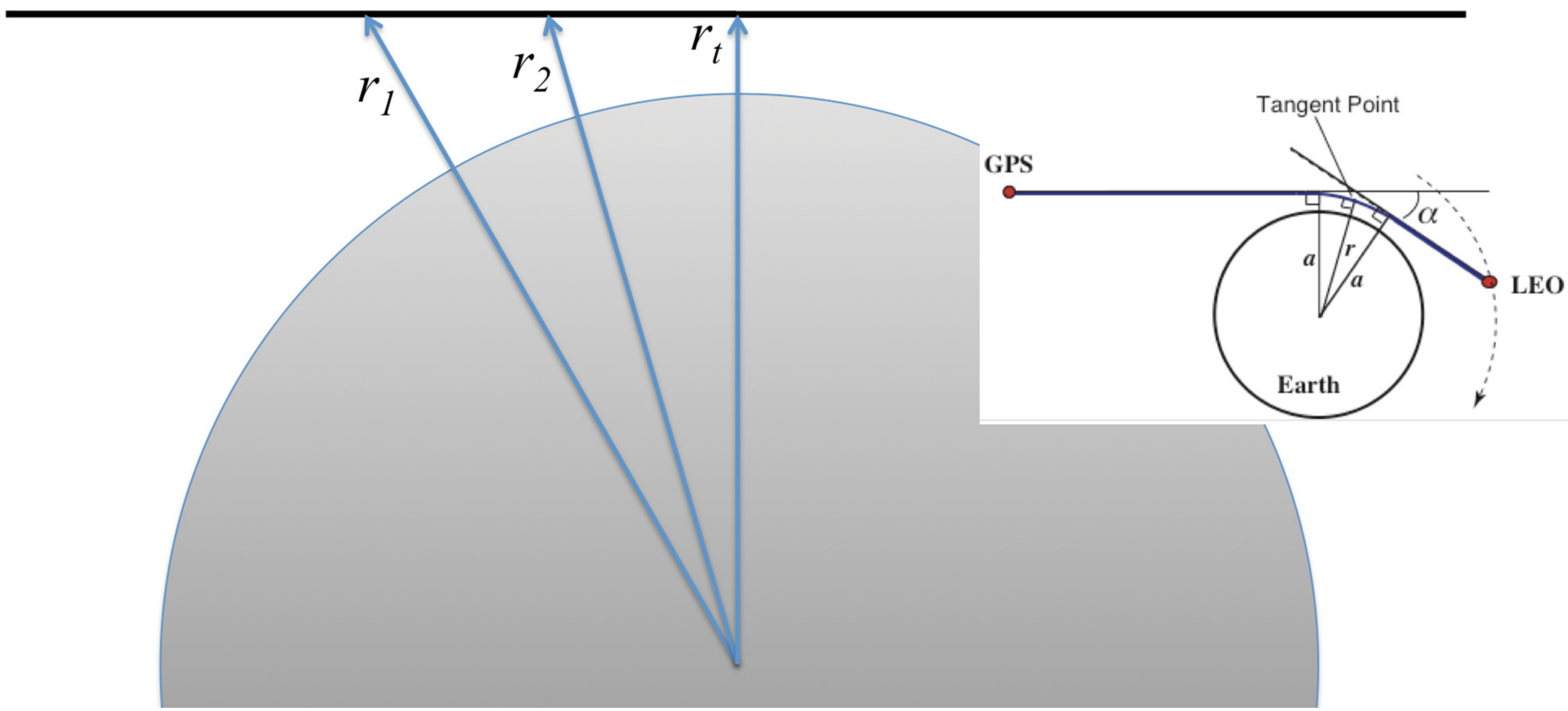
Below 2 km (tropics)
δT ~ 2 K
δPw ~10%



Bending Angle

$$\alpha(a) = 2\int_{r_t}^{\infty} \mathrm{d}\alpha = 2a\int_{r_t}^{\infty} \frac{1}{\sqrt{n^2 r^2 - a^2}} \frac{\mathrm{dln(n)}}{\mathrm{dr}} \mathrm{dr}$$

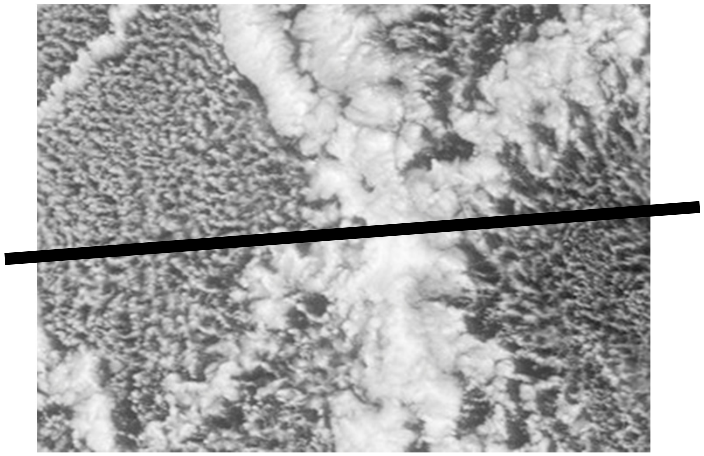
α – Bending angle
n – refractive index
r – radius or height
a – impact parameter



What's Missing?

- **Where is cloud top and base?**
- **What is horizontal variation near the raypath tangent point?**
- **Is the cloud top height changing along the raypath?**
- **What is the sea surface temperature?**

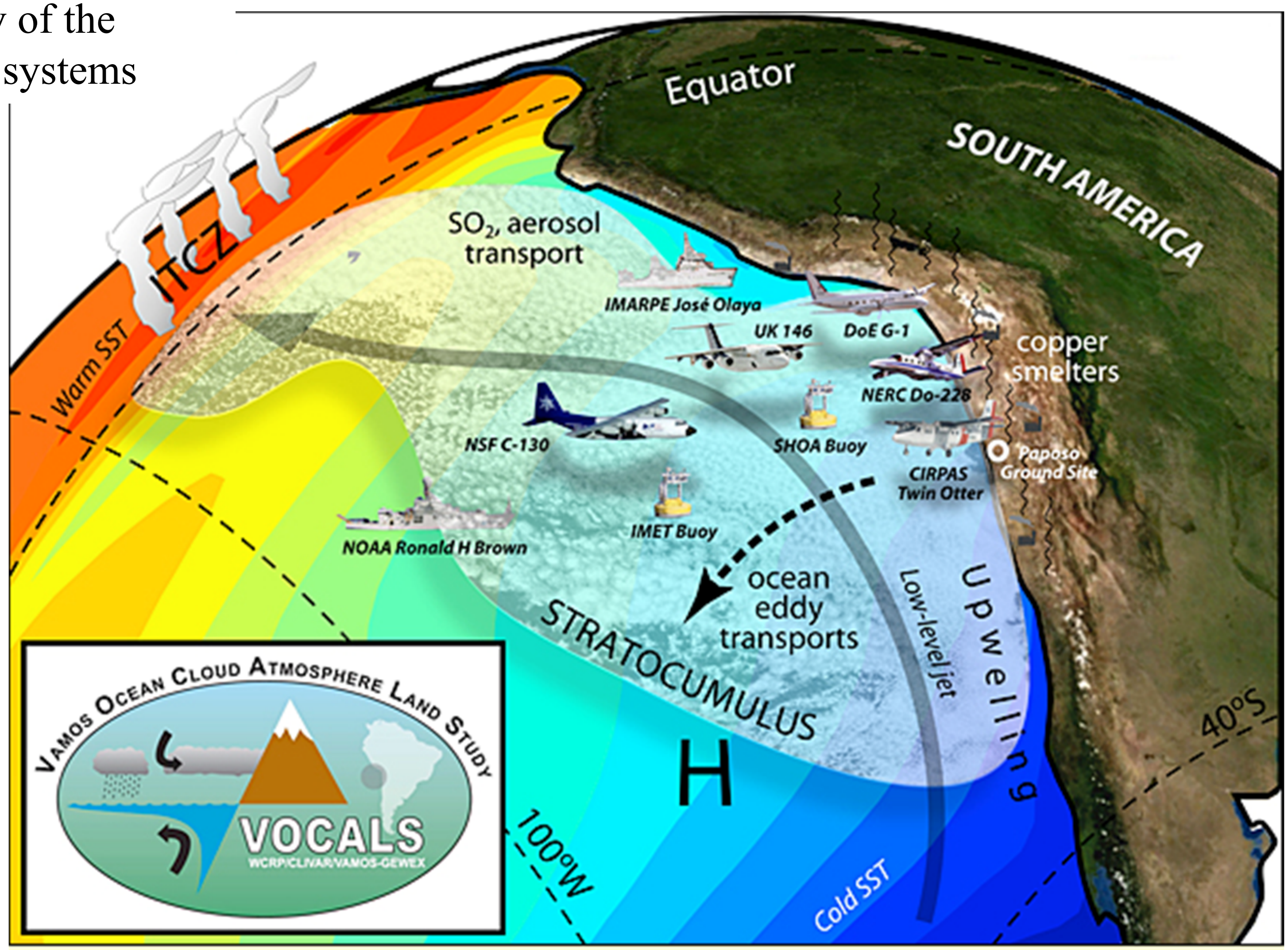
What processes govern the structure and variability of the cloudy atmospheric boundary layer?



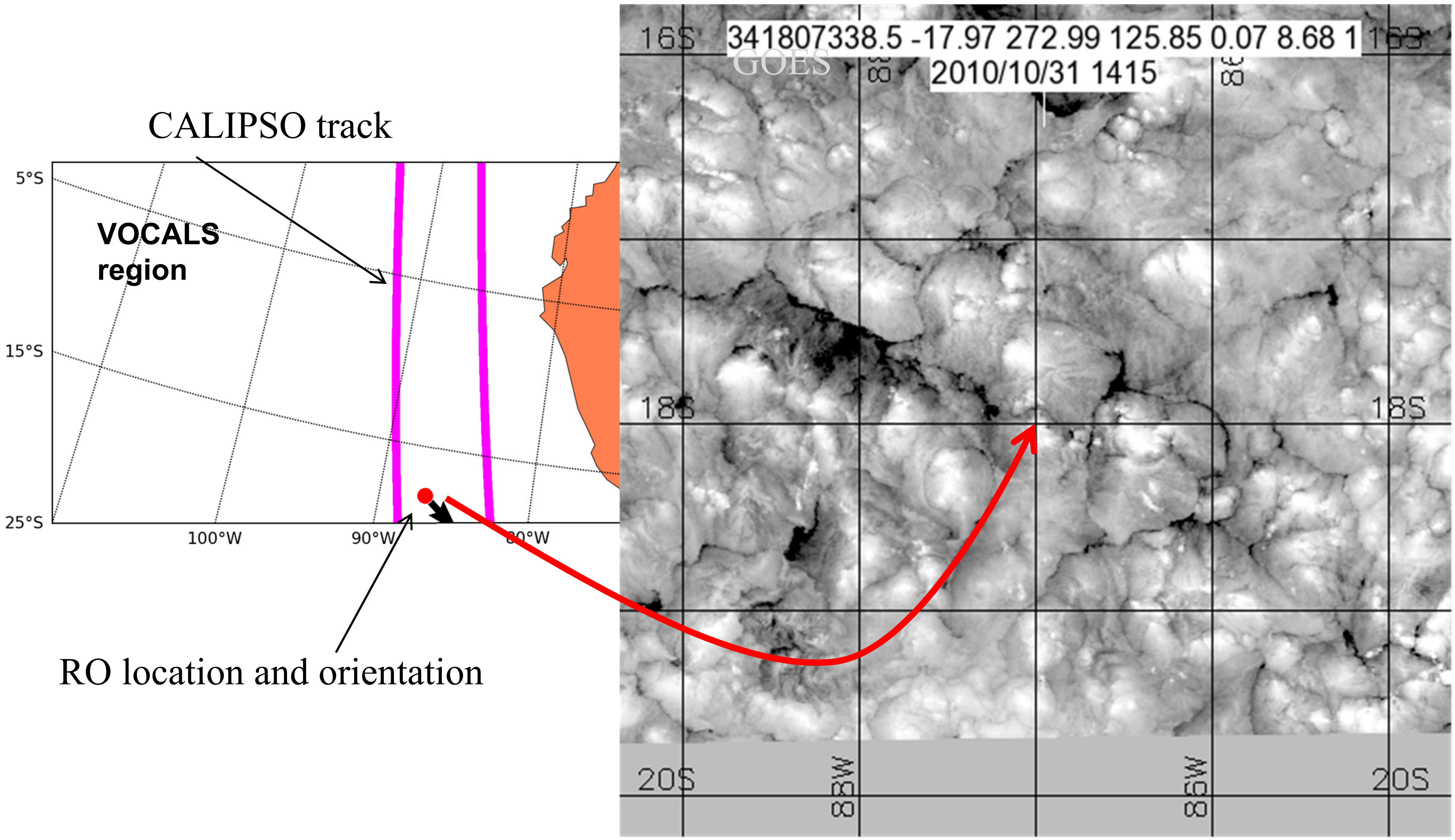
Case Study: VOCALS Region

VAMOS: Variability of the American monsoon systems

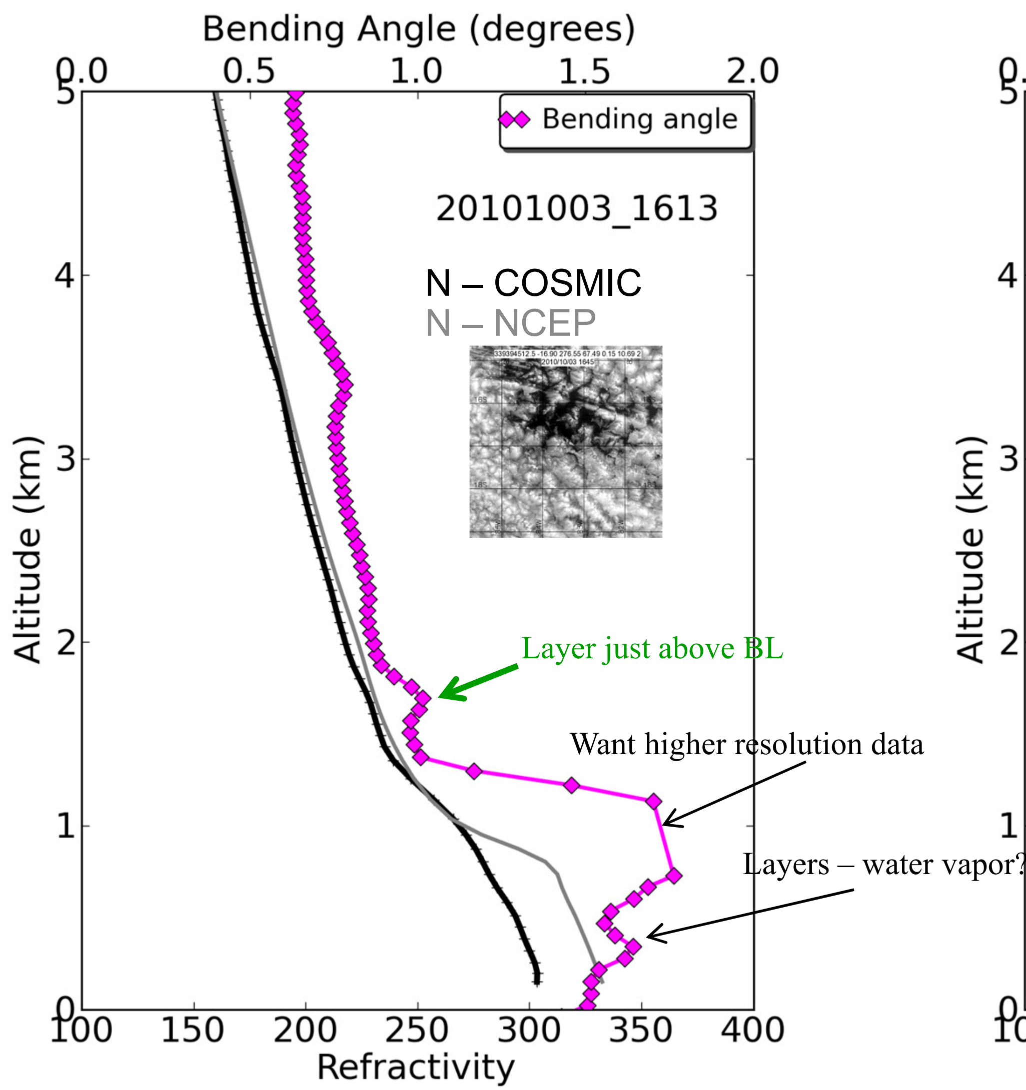
VAMOS
Ocean
Cloud
Atmosphere
Land
Study

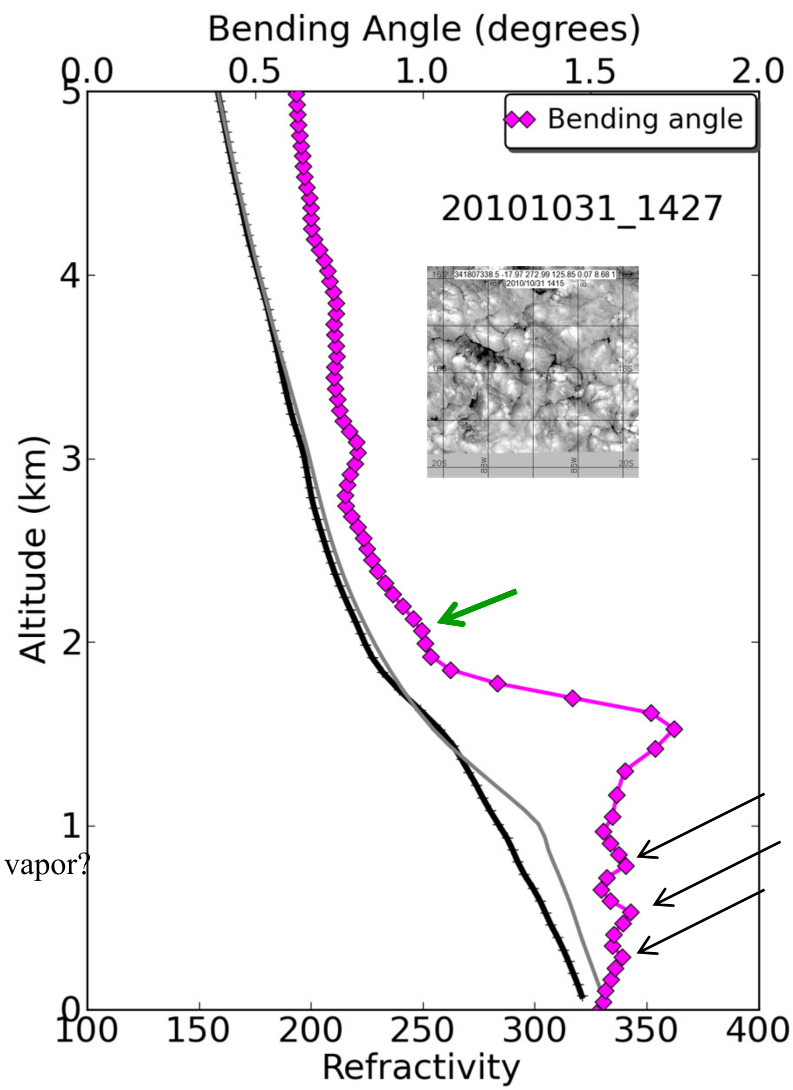


GOES + RO October 31, 2010



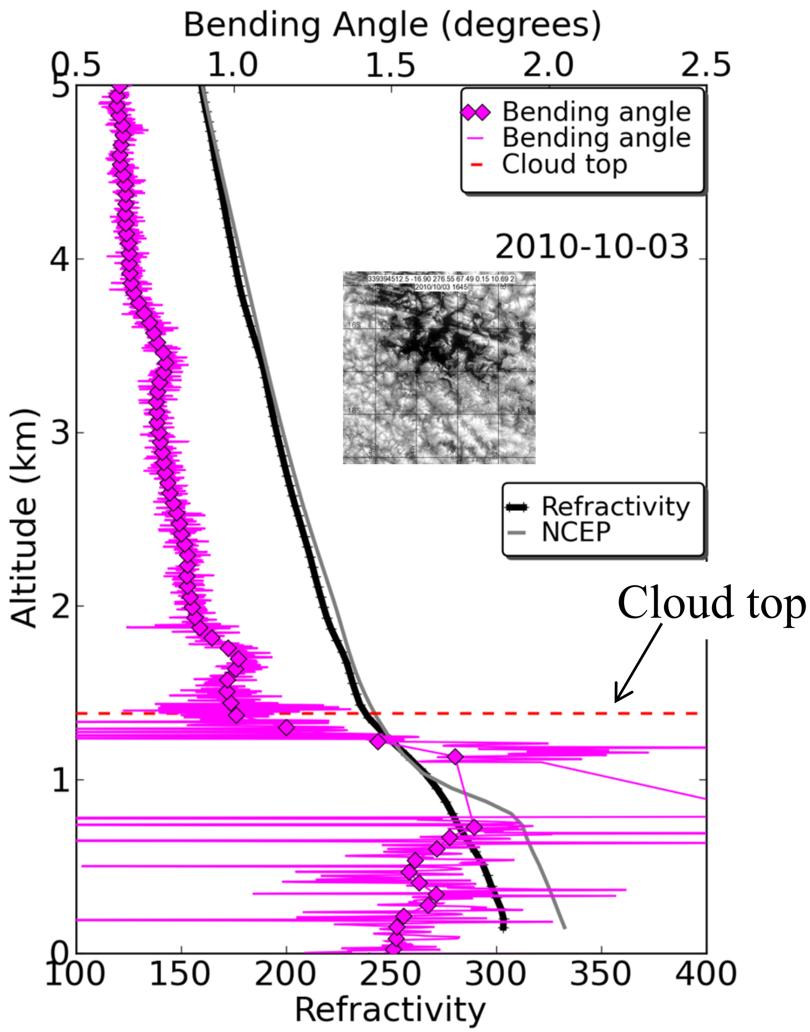
Refractivity And Bending Angle

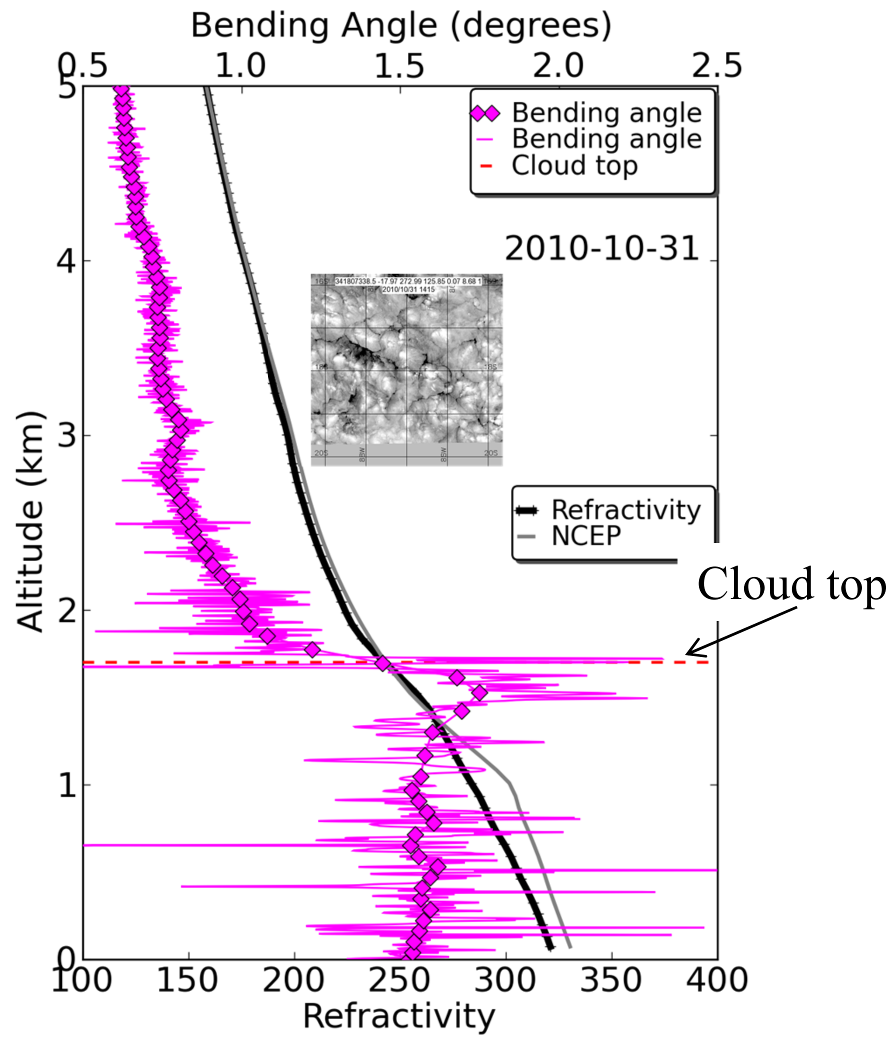


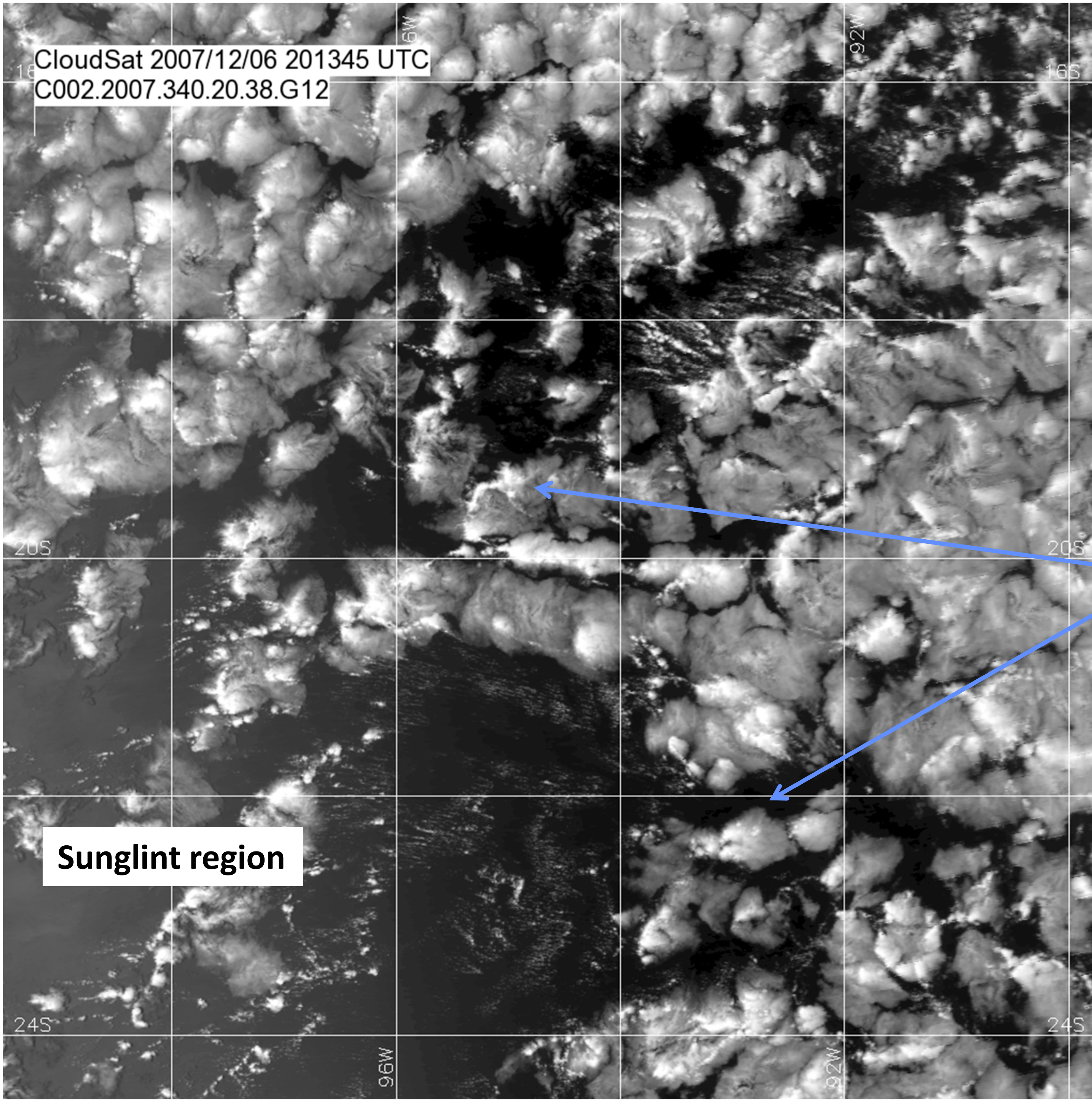


CALIPSO/CloudSat Information Added

Coincidence window: 2.7 hr, 51 km | 5.2 hr, 196 km







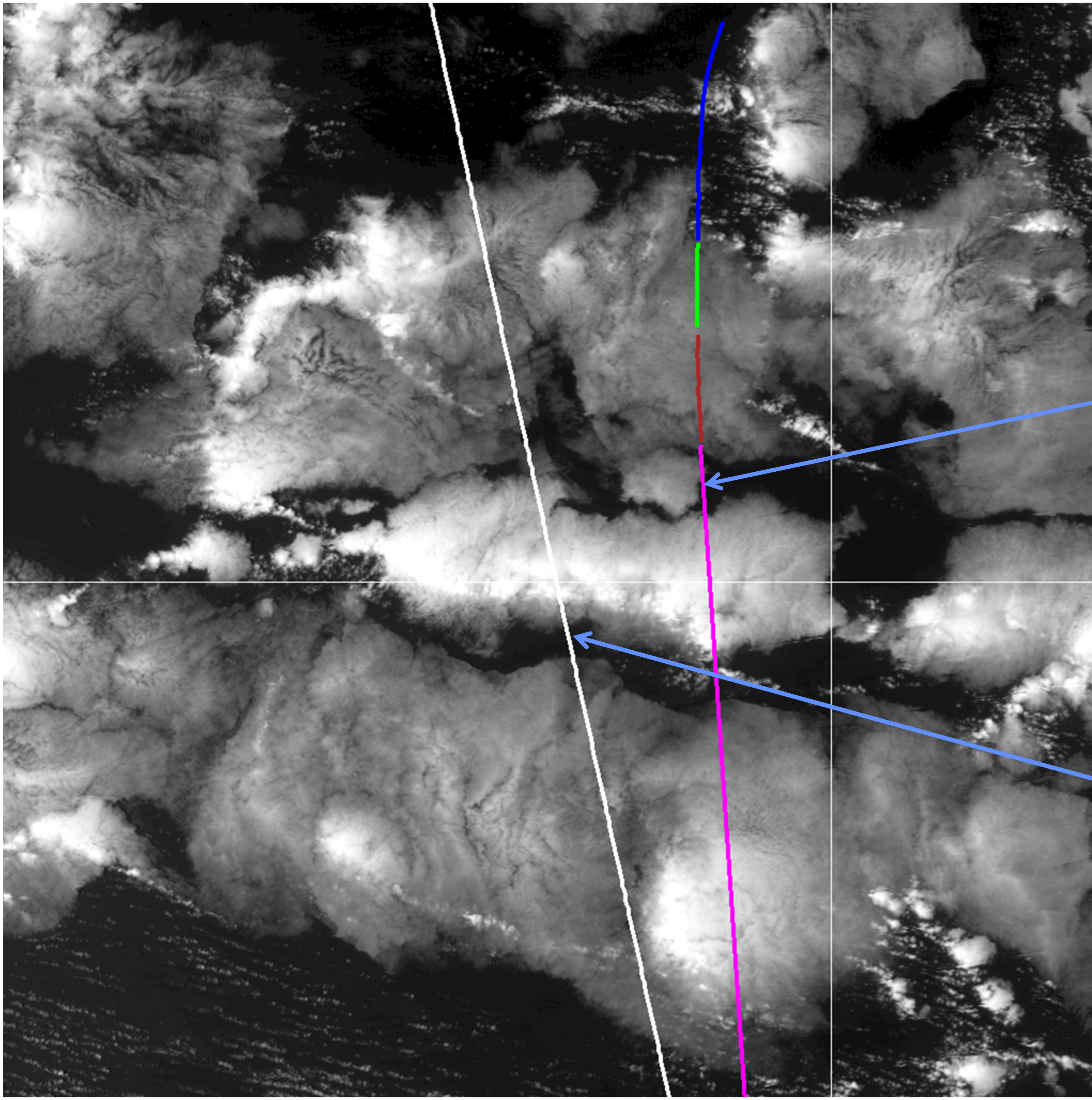
2007/12/06
MODIS 2010 UTC

19.9S 94.6W

Typical cellular cloud structure in mid-morning off the coast of South America

Pockets of open cells appear as drizzle begins

Stevens et. al. 2005: Pockets of open cells and drizzle in marine stratocumulus. *BAMS*, **86**, 51-57.



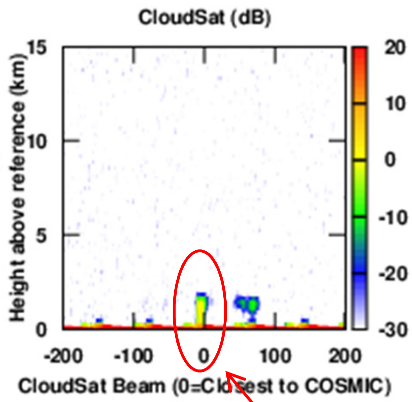
2007/12/06
MODIS 2010 UTC

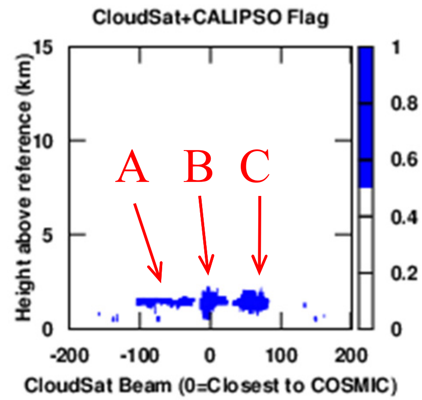
CloudSat 2014 UTC
COSMIC 2038 UTC

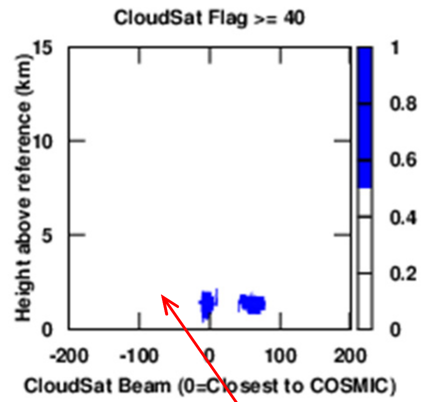
Trace of RO Tangent Point

MSL > 10 km
5 < MSL < 10
2 < MSL < 5 km
1 < MSL < 2 km
MSL < 1 km

CloudSat track
2 minutes
(400 km length)

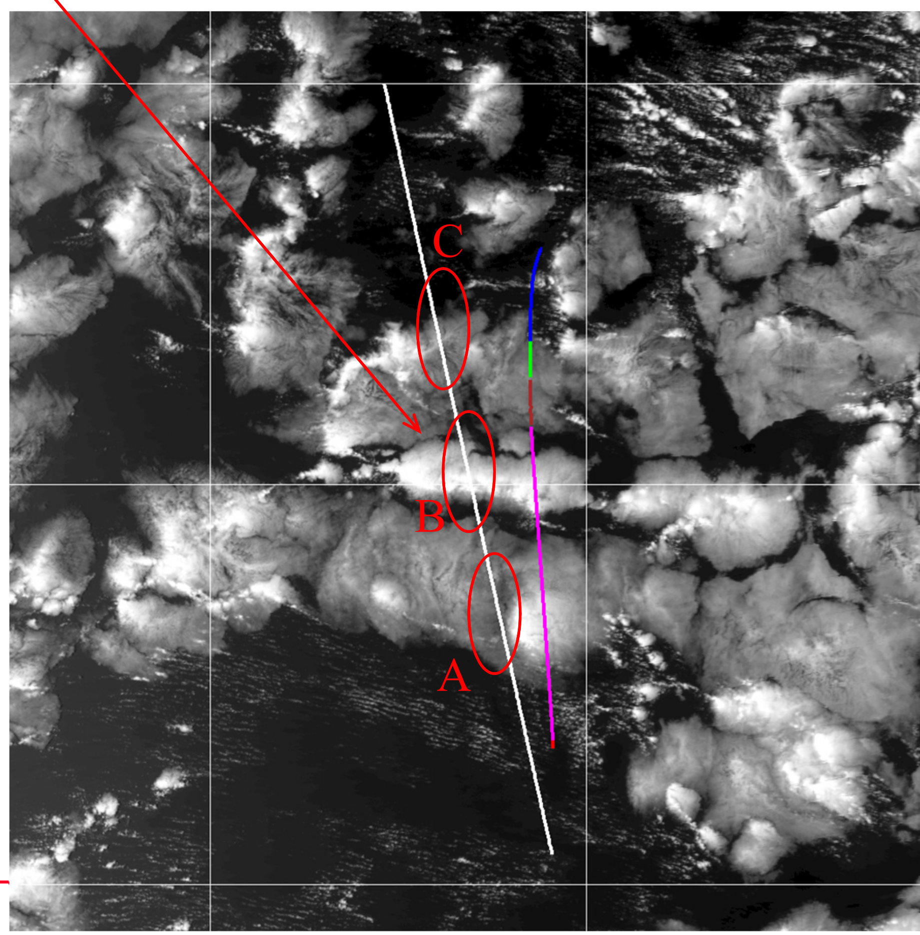






Blue indicates cloud presence

Along-track CloudSat vertical reflectivity profile



Region A does not trigger the CloudSat cloud mask flag

But it is detected by CloudSat+CALIPSO

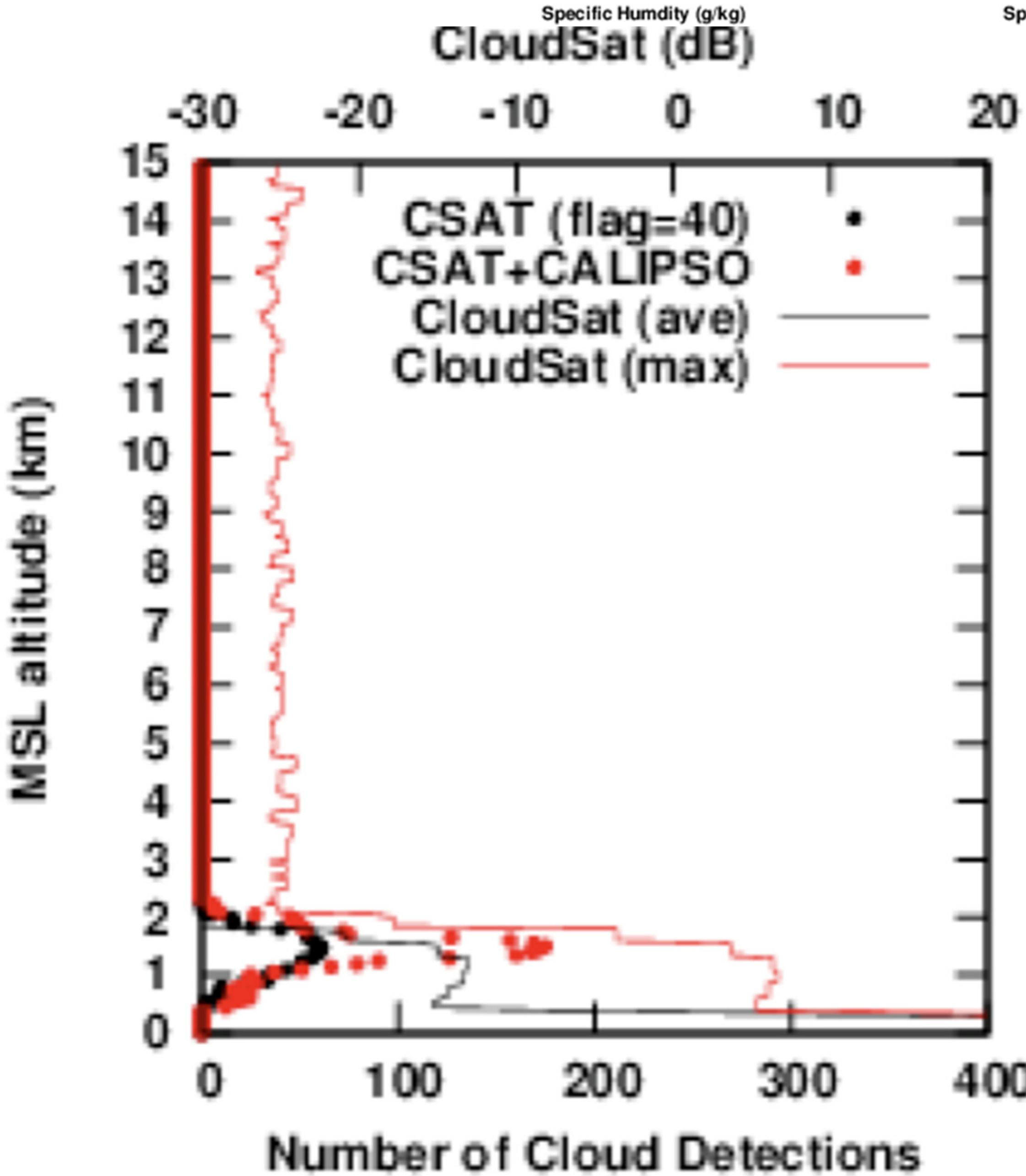
Region B is likely drizzle

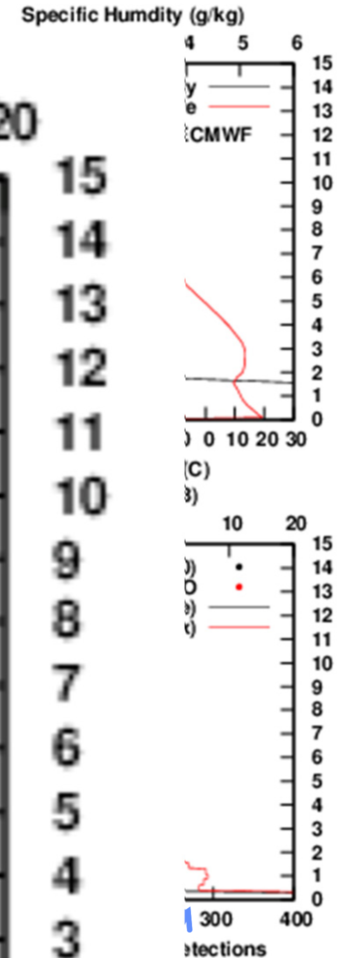
CloudSat transect covers three regions of open-cell structure

Cloud top height ~ 2 km

Retrieved COSMI(
ECMWF (right)

Note strong
bending ang
top height, t
constant val

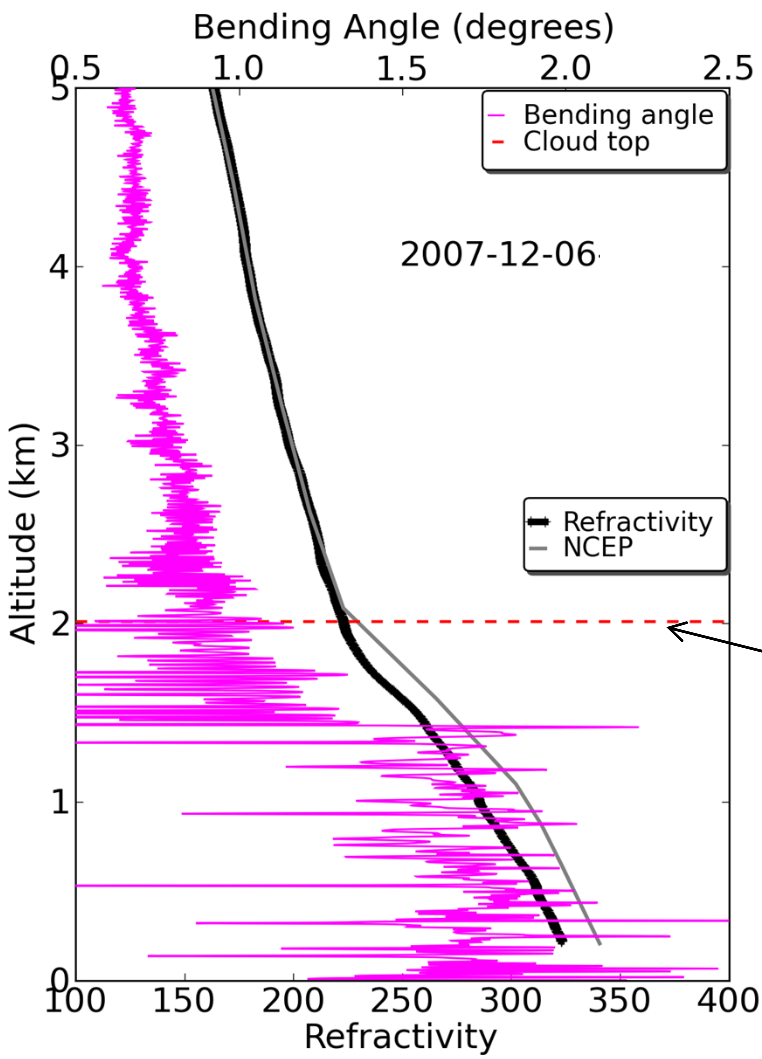




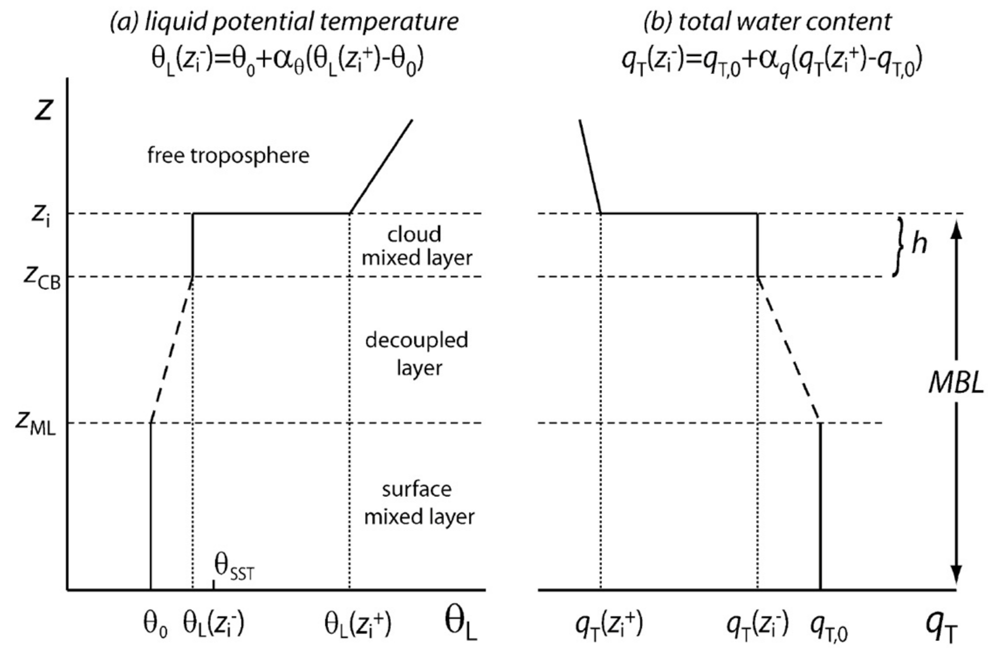
d line) in

CALIPSO/CloudSat Information Added

Coincidence window: 24 minutes, 10 km

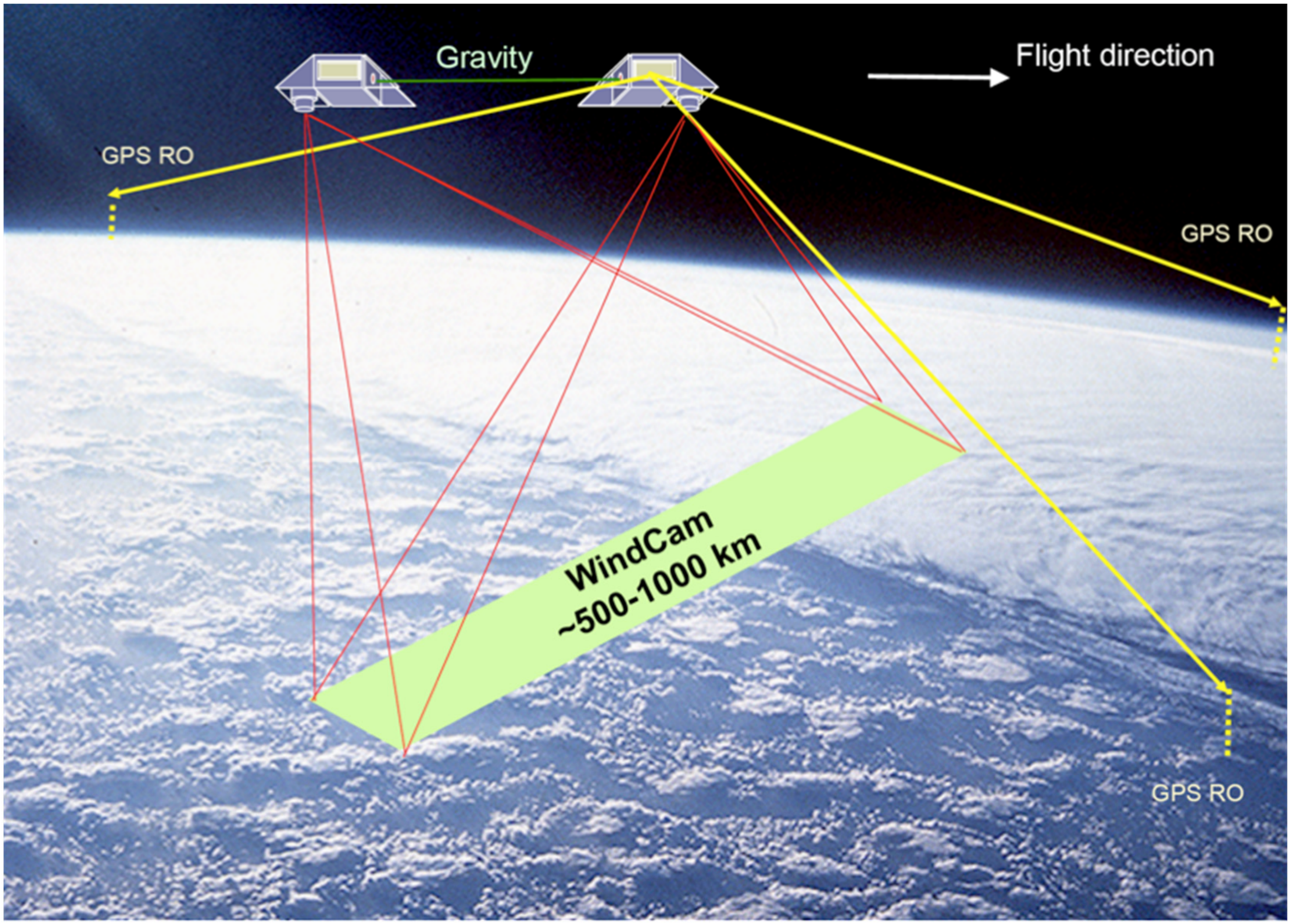


Cloud top

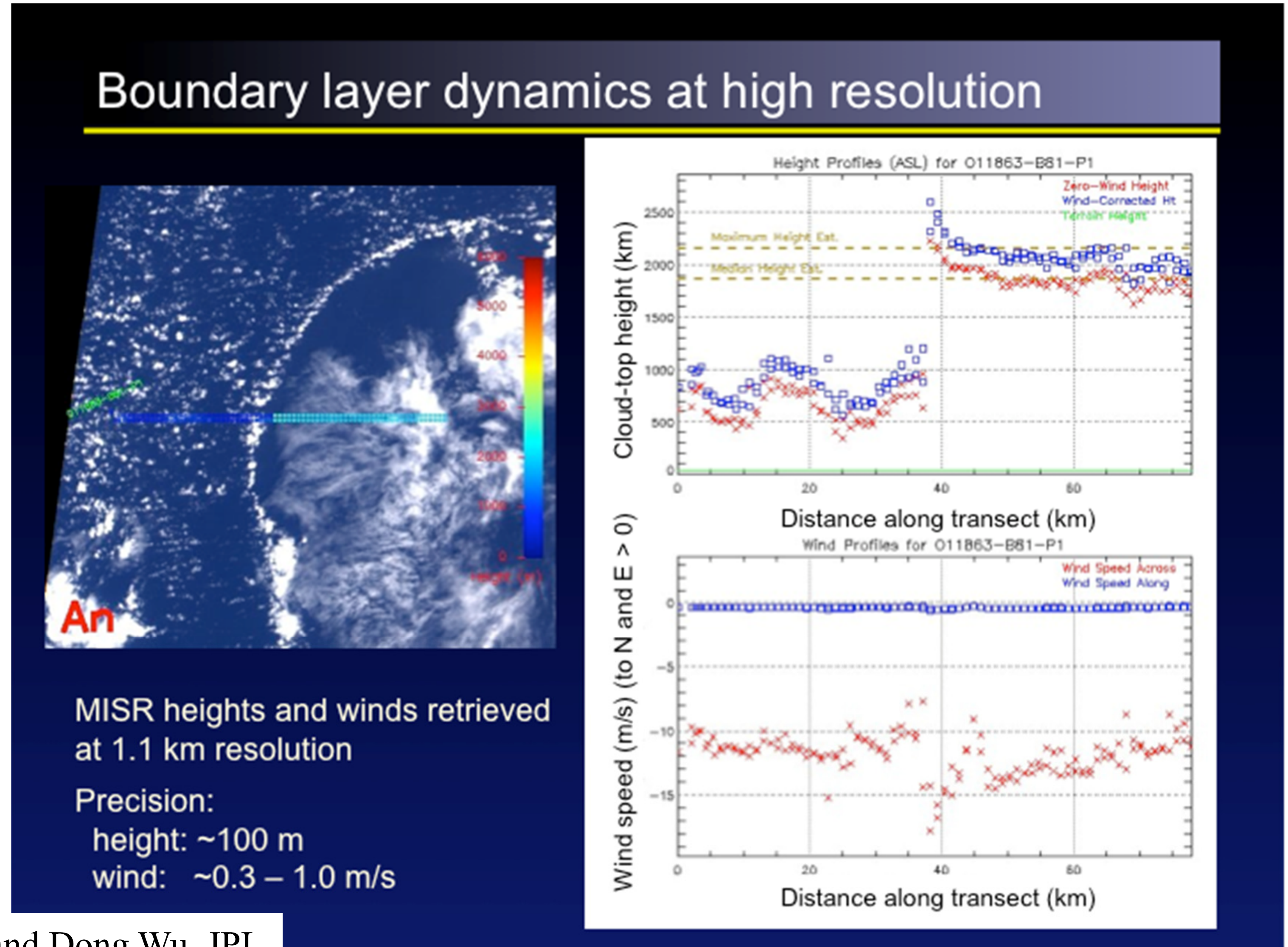


Wood and Bretherton, J Clim 2004

Combining Instruments



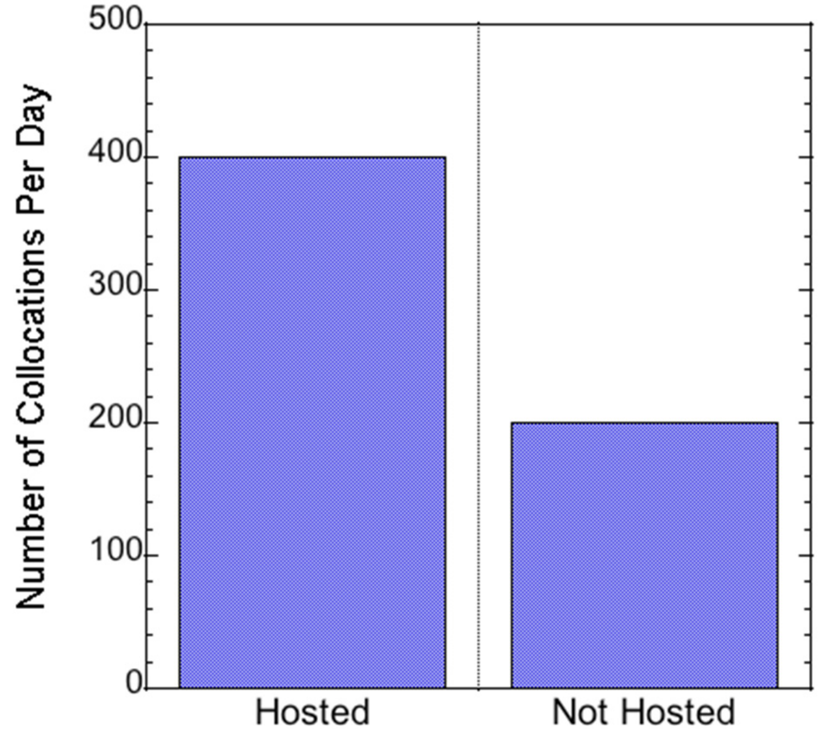
Cameras Provide Horizontal Resolution and Cloud Properties



Dave Diner and Dong Wu, JPL

Hosting RO on WindCam Vs Random Coincidences

- We estimate ~400 collocated profiles per day with RO hosted on WindCam satellite versus ~200 profiles per day for only coincidences with the planned COSMIC-2 constellation
  - COSMIC-2 is ~10,000 profiles per day
  - We assumed a 1000 km swath for WindCam
- Coincident measurements within ~7 minutes



Summary

- **Objective: significant progress in understanding low-cloud boundary layer processes**
  - **Single largest uncertainty in climate projections**
- **Radio occultation has *unique* features suited to boundary layer remote sensing**
  - **Cloud penetrating**
  - **Very high vertical resolution (~50m-100m)**
  - **Sensitivity to thermodynamic variables**
- **Way forward: combine RO with other sensors that have high horizontal resolution and are sensitive to key cloud properties**
  - **Variant of the Multi-angle Imaging Spectral Radiometer (MISR) that detects cloud type, cloud top height, and cloud top winds**
  - **RO w/ TriG (NASA Instrument) + WindCam**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Innovative Satellite Observations to Characterize the Cloudy Boundary Layer

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In 2007 the Intergovernmental Panel on Climate Change (IPCC) reiterated that "Cloud feedbacks remain the largest source of uncertainty" in climate projections. How clouds change in response to radiative forcing effectively determines the sensitivity of the Earth's temperature to increases in greenhouse gases. Clouds in the boundary layer, the lowermost region of the atmosphere adjacent to the Earth's surface, are known to play the key role in climate feedbacks that lead to these large uncertainties. Yet current climate models remain far from realistically representing the cloudy boundary layer, as they are limited by the inability to adequately represent the small-scale physical processes associated with turbulence, convection and clouds.

Although some relevant information can be obtained from existing measurements and missions, we remain far from directly observing the thermodynamic structure (e.g. temperature and water content) underneath clouds. Current efforts attempt to leverage information from platforms,

Study Co-Lead **Yuk Yung** from Caltech.

Study Co-Lead **Joao Teixeira** from JPL.

Study Co-Lead **Robert Wood** from the University of Washington.